Problems

26–4 and 26–5 Time Dilation, Length Contraction

1. (I) A spaceship passes you at a speed of $0.750c$. You measure its length to be 28.2 m. How long would it be when at rest?
2. (I) A certain type of elementary particle travels at a speed of 2.70×10^8 m/s. At this speed, the average lifetime is measured to be 4.76×10^{-6} s. What is the particle's lifetime at rest?
3. (I) Lengths and time intervals depend on the factor

$$\sqrt{1 - v^2/c^2}$$

according to the theory of relativity (Eqs. 26–1 and 26–3). Evaluate this factor for speeds of: (*a*) $v = 20{,}000$ m/s (typical speed of a satellite); (*b*) $v = 0.020c$; (*c*) $v = 0.200c$; (*d*) $v = 0.95c$; (*e*) $v = 0.98c$; (*f*) $v = 0.999c$.
4. (II) If you were to travel to a star 125 light-years from Earth at a speed of 2.50×10^8 m/s, what would you measure this distance to be?
5. (II) What is the speed of a pion if its average lifetime is measured to be 4.10×10^{-8} s? At rest, its average lifetime is 2.60×10^{-8} s.
6. (II) In an Earth reference frame, a star is 82 light-years away. How fast would you have to travel so that to you the distance would be only 35 light-years?
7. (II) Suppose you decide to travel to a star 85 light-years away at a speed that tells you the distance is only 25 light-years. How many years would it take you to make the trip?
8. (II) At what speed v will the length of a 1.00-m stick look 10.0% shorter (90.0 cm)?
9. (II) Escape velocity from the Earth is 40,000 km/h. What would be the percent decrease in length of a 95.2-m-long spacecraft traveling at that speed?
10. (II) At what speed do the relativistic formulas for (*a*) length and (*b*) time intervals differ from classical values by 1.00%? (This is a reasonable way to estimate when to do relativistic calculations rather than classical.)
11. (II) Suppose a news report stated that starship *Enterprise* had just returned from a 5-year voyage while traveling at $0.84c$. (*a*) If the report meant 5.0 years of *Earth time*, how much time elapsed on the ship? (*b*) If the report meant 5.0 years of *ship time*, how much time passed on Earth?
12. (II) A certain star is 10.6 light-years away. How long would it take a spacecraft traveling $0.960c$ to reach that star from Earth, as measured by observers: (*a*) on Earth, (*b*) on the spacecraft? (*c*) What is the distance traveled according to observers on the spacecraft? (*d*) What will the spacecraft occupants compute their speed to be from the results of (*b*) and (*c*)?
13. (II) A friend speeds by you in her "Ferrari" spacecraft at a speed of $0.660c$. It is measured in your frame to be 4.80 m long and 1.25 m high. (*a*) What will be its length and height at rest? (*b*) How many seconds would you say elapsed on your friend's watch when 20.0 s passed on yours? (*c*) How fast did you appear to be traveling according to your friend? (*d*) How many seconds would she say elapsed on your watch when she saw 20.0 s pass on hers?
14. (III) How fast must an average pion be moving to travel 15 m before it decays? The average lifetime, at rest, is 2.6×10^{-8} s.

26–7 Relativistic Momentum

15. (I) What is the momentum of a proton traveling at $v = 0.85c$?
16. (I) At what speed will an object's relativistic mass be twice its rest mass?
17. (II) A particle of rest mass m_0 travels at a speed $v = 0.20c$. At what speed will its momentum be doubled?
18. (II) (*a*) A particle travels at $v = 0.10c$. By what percentage will a calculation of its momentum be wrong if you use the classical formula? (*b*) Repeat for $v = 0.50c$.
19. (II) What is the percent change in momentum of a proton that accelerates (*a*) from $0.45c$ to $0.90c$, (*b*) from $0.90c$ to $0.98c$?

26–9 $E = mc^2$

20. (I) A certain chemical reaction requires 4.82×10^4 J of energy input for it to go. What is the increase in mass of the products over the reactants?
21. (I) When a uranium nucleus at rest breaks apart in the process known as fission in a nuclear reactor, the resulting fragments have a total kinetic energy of about 200 MeV. How much mass was lost in the process?
22. (I) Calculate the rest energy of an electron in joules and in MeV $(1\text{ MeV} = 1.60 \times 10^{-13}\text{ J})$.
23. (I) Calculate the rest mass of a proton in MeV/c^2.
24. (I) The total annual energy consumption in the United States is about 8×10^{19} J. How much mass would have to be converted to energy to fuel this need?
25. (II) How much energy can be obtained from conversion of 1.0 gram of mass? How much mass could this energy raise to a height of 0.25 km above the Earth's surface?
26. (II) What is the speed of a particle when its kinetic energy equals its rest energy?
27. (II) At what speed will an object's kinetic energy be 25% of its rest energy?
28. (II) (*a*) How much work is required to accelerate a proton from rest up to a speed of $0.997c$? (*b*) What would be the momentum of this proton?
29. (II) Calculate the kinetic energy and momentum of a proton traveling 2.60×10^8 m/s.
30. (II) What is the momentum of a 750-MeV proton (that is, its kinetic energy is 750 MeV)?
31. (II) What is the speed of a proton accelerated by a potential difference of 105 MV?